

# 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive

User Manual

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# 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive

## User Manual

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The following revision history table summarizes the changes contained in this document. For your convenience, the page number designators have been linked to the appropriate location.

## Revision History

Date	Revision Level	Description	Page Number(s)
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# Chapter 1

## Introduction

### 1.1 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive Outline

Freescale's 3-Phase BLDC (Brushless DC) / PMSM (Permanent Magnet Synchronous Motor) Low-Voltage Motor Control Drive is a 12–24 V DC, 4 A, off-line power stage that, as a main board together with a daughter board, creates a single unit for developing BLDC/PMSM motor control applications.

With one of the available daughter boards, accommodating a selected microcontroller, it provides a ready-made, software-development platform for one-third horsepower off-line motors. Feedback signals are provided that allow a variety of algorithms to control 3-phase PMSM and BLDC motors.

[Figure 1-1](#) shows an illustration of the system architecture. [Figure 1-2](#) is a picture of the main board.

The board features:

- Power supply voltage input 12–24 V DC, extended up to 50 V (see chapter [2.2 Electrical Characteristics](#) for details)
- Output current 4 A
- Power supply reverse polarity protection circuitry
- 3-phase bridge inverter (6 MOSFET's)
- 3-phase MOSFET gate driver with overcurrent and undervoltage protection
- 3-phase and DC-bus-current-sensing shunts
- DC-bus voltage sensing
- 3-phase back-EMF voltage-sensing circuitry
- Low-voltage on-board power supplies
- Encoder/hall sensor sensing circuitry
- Motor power and signal connectors
- 2 connectors for daughter board connection
- CAN physical layer
- USB interface
- User LED, power-on LED, 6 PWM LED diodes, and SCI activity LED diodes
- Up, down, toggle switches
- Reset push-button

### 1.2 About This Manual

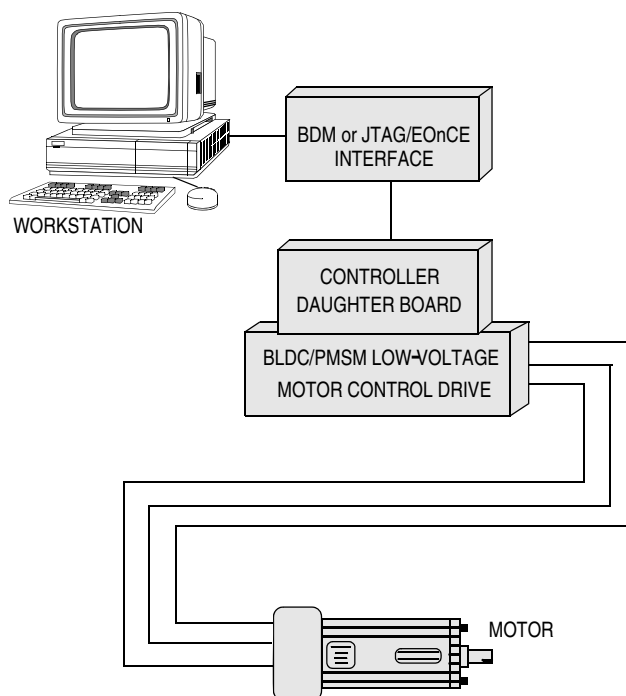
Key items are in the following locations in this manual:

- Setup instructions — [1.4 Setup Guide](#)
- Schematics — [Appendix A. 3-Phase BLDC/PMSM Motor Control Drive Schematics](#)
- Pin assignments — [Chapter 3 Pin Description](#)

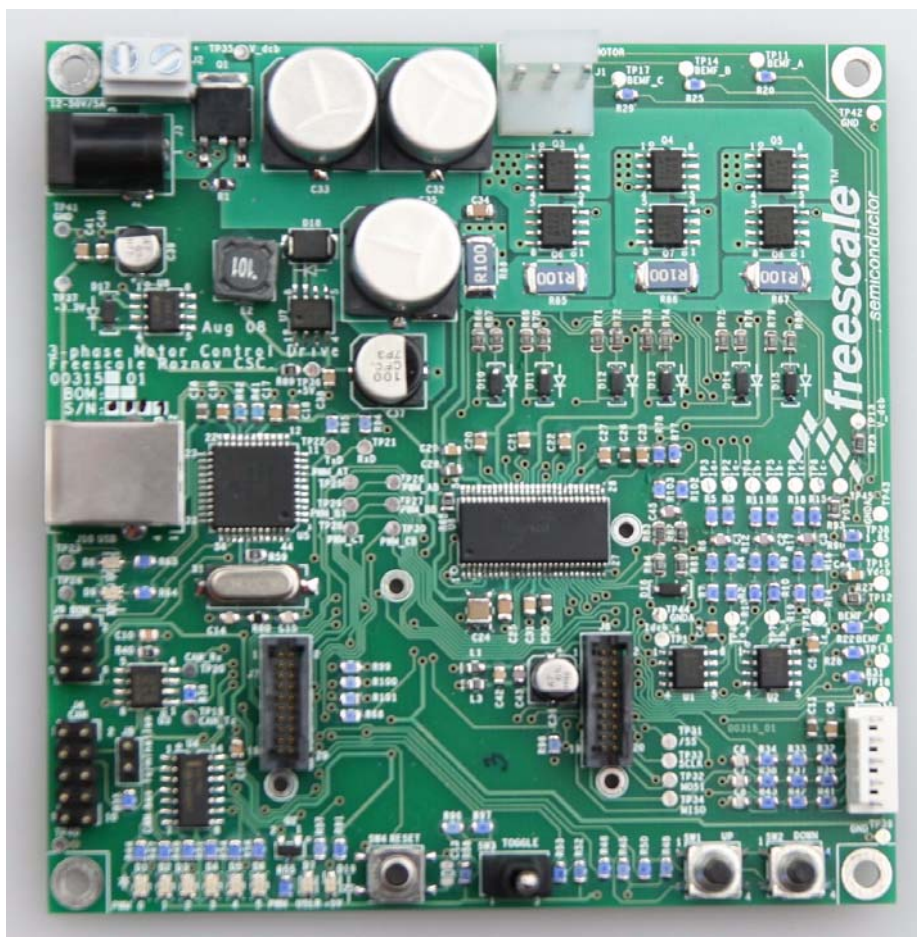
3-Phase BLDC/PMSM Low-Voltage Motor Control Drive, Rev. 0

## About This Manual

- Pin-by-pin description — [3.2 Signal Descriptions](#)
- Description of reference design aspects of the board's circuitry — [Chapter 4 Design Consideration](#)



**Figure 1-1 System Configuration**



**Figure 1-2 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive**

## 1.3 Warnings

This development-tool set operates in an environment that includes rotating machinery.

Be aware:

- Wear safety glasses, avoid ties and jewelry, use shields.
- Power devices and the motor can reach temperatures hot enough to cause burns.

## 1.4 Setup Guide

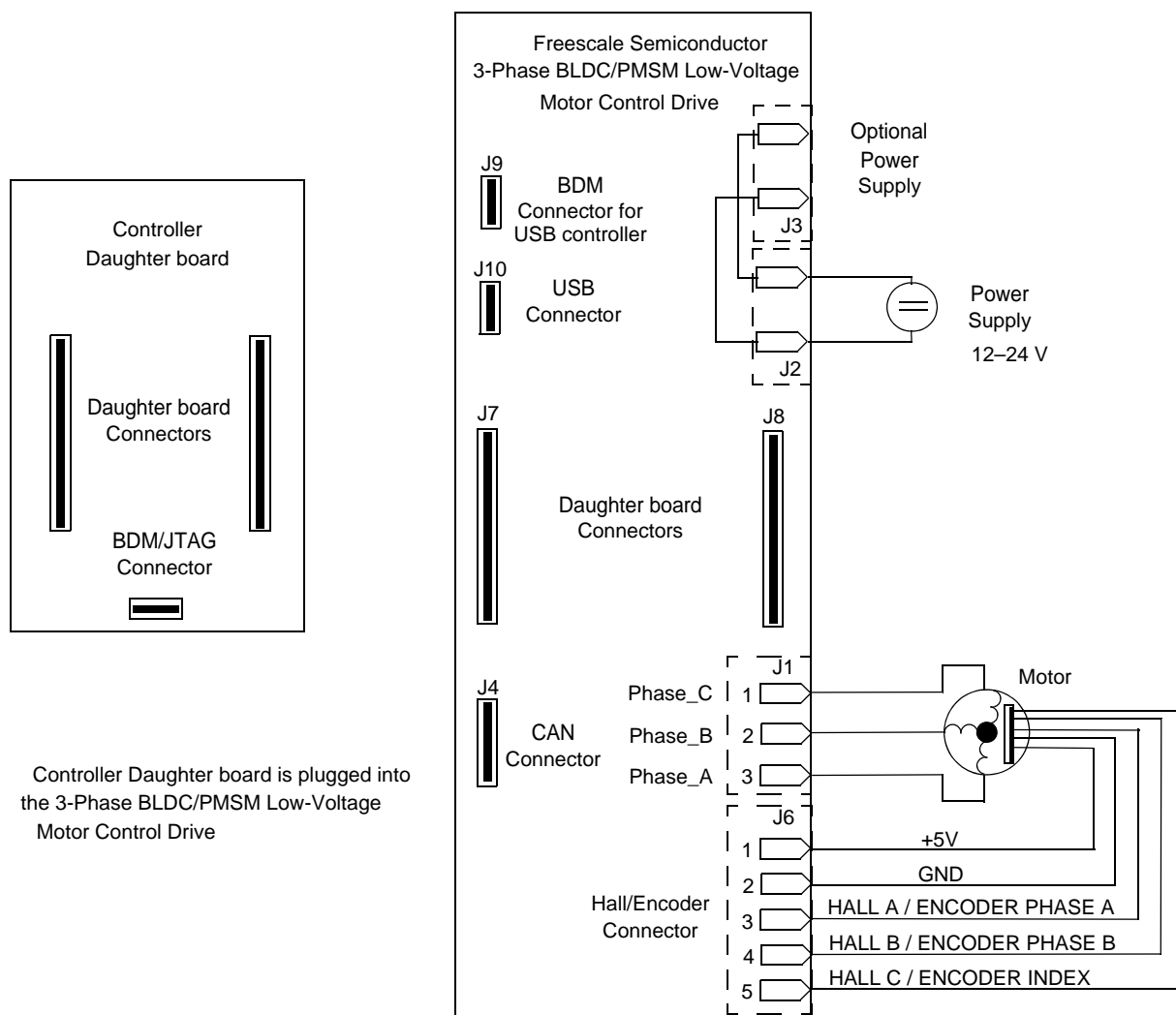
Setup and connections for the 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive (main board) are straightforward. A controller daughter board connects to the main board via two 20-pin daughter board connectors. The system can be powered by a 12–24 V DC power supply. For safety reasons, and ease of making measurements, use a regulated DC power supply. Limit the power supply to under 5 A. [Figure 1-3](#) depicts a complete setup.

The step-by-step setup procedure is as follows:

1. Plug a controller daughter board into the main board.
2. Connect the motor connector to the output connector J1, located along the back edge of the board. Phase A, phase B, and phase C are labelled on the bottom of the board.
3. For BLDC motors, it is important to put the wire color coded for phase A into the connector terminal labelled A, and so on for phase B and phase C.
4. Connect an encoder or hall sensor connector to the encoder/hall sensor interface J6.
5. Connect a current-limited DC power supply to connector J2 or J3, located on the left back edge of the board. The input voltage range is 12–24 V DC. Current limit should be set for less than 5 A. Only one power input is required.
6. Apply power to the main board. The green power-on LED D19 located on the front edge lights. The main board powers the controller daughter board.
7. Plug a standard AB-type USB cable into your PC and into the 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive. Then install the USB driver onto your PC to enable using FreeMASTER. Follow the instructions in the USB\_driver\_install.doc to properly install the USB driver.

### **WARNING**

***If an input voltage higher than 24 V is applied, the controller daughter board can be damaged.***



**Figure 1-3 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive Setup**





# Chapter 2

## Operational Description

### 2.1 Introduction

Freescale's 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive is a 3-phase power stage that will operate with DC input voltages in the range 12–24 V, 4 A. Together with the daughter boards, it provides a software-development platform that allows algorithms to be written and tested without designing and building any hardware. It supports a variety of algorithms for PMSM and brushless DC (BLDC) motors.

The 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive contains reverse-polarity protection circuitry, MOSFET-gate-drive circuits, analog-signal conditioning, low-voltage power supplies and bridge MOSFETs. The power devices do not need to be mounted on a heatsink.

Figure 2-1 shows a block diagram. The daughter board is connected via two 20-pin rib-cage connectors, J7 and J8. Figure 3-1 shows pin assignments for the daughter board connectors. Power connections to the motor are made on output connector J1. Phase A, phase B, and phase C are labelled A, B, and C. Power requirements are met by a single external 12 V to 50 V DC power supply. Either input is supplied through connector J2 or J3. All connectors are marked on the bottom side of the board.

Current-measuring circuitry is set up for 4 A full scale. Both bus and phase leg currents are measured. An overcurrent trip point is set at 3.75 A.

There are controller daughter boards available with these controllers:

- MC56F8013/23 — LQFP32
- MC9S08AC16 — LQFP44
- MCF51AC256 — LQFP80
- MC9S08MP16 — LQFP48
- MC56F8006 — LQFP32

More controller daughter boards are planned. Check the website [www.freescale.com](http://www.freescale.com) for more information.

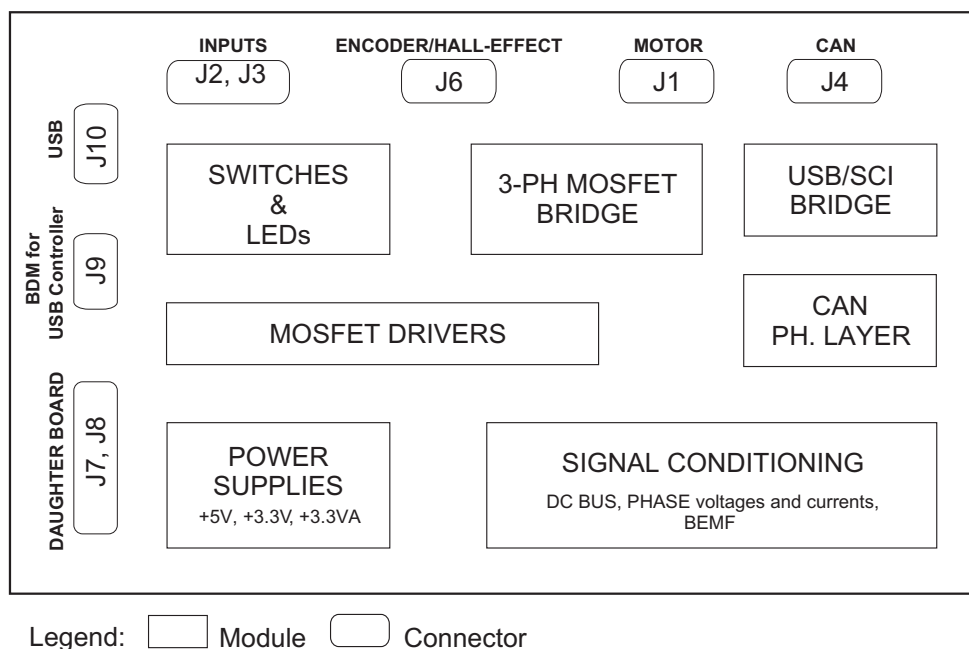


Figure 2-1 Block Diagram

## 2.2 Electrical Characteristics

The electrical characteristics in [Table 2-1](#) apply to operations at 25 °C with a 24 V DC power supply voltage. Maximal value of the input voltage can be higher than 24 V. A 50 V maximal input voltage value is allowed, but the DC-bus and BEMF sensing circuits need to be modified. The divider resistors in these circuits need to be changed to change sensing range up to 50 V, if required. It prevents scaled quantities exceeding the maximum-allowed input voltage value on the controller input pins.

### **WARNING**

***If an input voltage higher than 24 V is applied, the controller daughter board can be damaged.***

Table 2-1 Electrical Characteristics

Characteristic	Symbol	Min	Typ	Max	Units
DC input voltage	$V_{dc}$	12	—	24	V
Quiescent Current*	$I_{CC}$	—	TBD	—	mA
Logic 1 Input Voltage	$V_{IH}$	1.5	—	1.7	V
Logic 0 Input Voltage	$V_{IL}$	0.9	—	1	V
Input Resistance	$R_{In}$	—	10	—	k $\Omega$
Analog Output Range	$V_{Out}$	0	—	3.3	V
Bus Current Sense Voltage	$I_{Sense}$	—	413	—	mV/A
Bus Current Sense Offset	$I_{offset}$		+1.65		V
Bus Voltage Sense Voltage*	$V_{Bus}$	—	91	—	mV/V
Bus Voltage Sense Offset	$V_{offset}$		0		V
Bus Continuous Output Current **	$I_C$	—	—	3.75	A
Total Power Dissipation (per MOSFET) ***	$P_D$	—	—	TBD	W
Dead Time (set by SW MC33927) ****	$t_{off}$	0	—	15	us

\* Full sensing range 3.3 V corresponds to 36.3 V.

\*\* Overcurrent threshold is set at this level.

\*\*\* The values were measured at 25 °C, for other temperatures the values may be different.

\*\*\*\* Default dead time is 15  $\mu$ s. Dead time depends on the timebase of the MC33927.



# Chapter 3

## Pin Description

### 3.1 Introduction

Inputs and outputs are located on nine connectors and headers available on the board:

- Three-pin motor connector J1
- Two power supply input connectors J2 and J3
- CAN header J4
- Encoder/hall-effect connector J6
- Two 20-pin daughter board connectors J7 and J8
- USB controller BDM (Background Debugger Monitor) tool header J9
- USB connector J10

Pin descriptions for each connector and header are identified in the following information. [Figure 3-1](#) shows the pin assignments for the daughter board connectors J7 and J8. [Table 3-4](#) and [Table 3-5](#) show the signal descriptions.

The 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive contains several connectors and headers that serve for the connection of a power supply, for motor phases connection, and other functions.

The input power supply, attached to the J2 or J3 input, must be in the range of 12–50 V DC.

The output for the motor is done by the three-way connector J1. See [3.2.1 Motor Connector J1](#) for more details.

Each connector and header is labelled from the bottom side of the board.

### 3.2 Signal Descriptions

Pin descriptions are identified in this subsection.

#### 3.2.1 Motor Connector J1

Power outputs to the motor are located on connector J1. Phase outputs are labelled A, B, and C. [Table 3-1](#) contains pin assignments. Section [1.4 Setup Guide](#) shows how to connect the motor. On a permanent magnet synchronous motor, any of the 3-phase windings can be connected here. For brushless DC motors, you must connect the wire color coded for phase A into the connector terminal labelled A, and so on for phase B and phase C.

**Table 3-1 Motor Connector J1 — Signal Descriptions**

Pin #	Signal Name	Description
1	C	Supplies power to motor phase C.
2	B	Supplies power to motor phase B.
3	A	Supplies power to motor phase A.

### 3.2.2 Power Supply Input Connectors J2 and J3

The power supply input connectors, labelled J2 and J3, are located at the left back corner of the board. They accept DC voltages from 12 V to 50 V / 5 A maximum. The J2 connector is a two-wire connector, the J3 connector is a 2.1 mm power jack for plug-in type DC power supply connections. The power supply polarity label for connector J2 is located on the bottom side. The board has reverse polarity protection.

Power applied to the board is indicated by a green color +5 V LED. This LED is the nearest one located to the reset switch.

### 3.2.3 CAN Header J4

This shows the CAN (Controller Area Network) bus header pin description. The CAN interface is located on the left edge of the board.

**Table 3-2 CAN Header J4 — Signal Descriptions**

Pin #	Signal Name	Description
1	No Connect	
2	No Connect	
3	CANL	Low-level CAN voltage input/output
4	CANH	High-level CAN voltage input/output
5	GND	Power supply ground
6	No Connect	
7	No Connect	
8	No Connect	
9	No Connect	
10	No Connect	

### 3.2.4 Encoder/Hall-Effect Interface J6

The 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive contains an encoder/hall-effect interface for position and speed sensing. The encoder/hall-effect interface is located on the right edge of the board. The circuit is designed to accept +3.3 V to +5 V encoder or hall-effect sensor inputs. Input noise filtering is supplied on the input path to the encoder/hall-effect interface. [Table 3-4](#) shows the encoder/hall-effect interface pin description.

**Table 3-3 Encoder/Hall-Effect Interface J6 — Signal Descriptions**

Pin #	Signal Name	Description
1	+5V	Supplies power from the board to either encoder or hall sensors.
2	GND	Encoder or hall sensors' ground.
3	PHASE A	Encoder or hall sensors' phase A input.
4	PHASE B	Encoder or hall sensors' phase B input.
5	INDEX	Encoder, index, or hall sensors' C input.

### 3.2.5 Daughter Board Connectors J7 and J8

Signal inputs and outputs for interconnection with different types of daughter boards are situated on two 20-pin connectors, located on the board's front side. [Figure 3-1](#) shows pin assignments. This figure shows the physical layout of the connectors. The physical view assumes that the board is oriented in such way that its title can be read from left to right. [Table 3-4](#) and [Table 3-5](#) contain lists of signal descriptions for connectors J7 and J8.

**Table 3-4 Daughter Board Connector J7 — Signal Descriptions**

Pin #	Signal Name	Description
1	GND	Digital and power ground.
2	+3.3V	Digital +3.3 V power supply.
3	CANTX	CAN transmit-data input.
4	CANRX	CAN receive-data output.
5	PWM_AT	Gate-drive signal for the top half-bridge of phase A. A logic low turns on phase A's top switch.
6	PWM_AB	Gate-drive signal for the bottom half-bridge of phase A. A logic high turns phase A's bottom switch on.
7	PWM_BT	Gate-drive signal for the top half-bridge of phase B. A logic low turns on phase B's top switch.
8	PWM_BB	Gate-drive signal for the bottom half-bridge of phase B. A logic high turns phase B's bottom switch on.

**Table 3-4 Daughter Board Connector J7 — Signal Descriptions**

Pin #	Signal Name	Description
9	PWM_CT	Gate-drive signal for the top half-bridge of phase C. A logic low turns on phase C's top switch.
10	PWM_CB	Gate-drive signal for the bottom half-bridge of phase C. A logic high turns phase C's bottom switch on.
11	OC	Overcurrent signal from 3-phase bridge driver.
12	INT	Interrupt signal from 3-phase bridge driver.
13	TxD	TxD signal between the JM60 and daughter board.
14	RxD	RxD signal between the JM60 and daughter board.
15	TOGGLE_SWITCH_ON1	Toggle-switch input (switch in position ON1).
16	TOGGLE_SWITCH_ON2	Toggle-switch input (switch in position ON2).
17	UP_SWITCH	Up switch input.
18	DOWN_SWITCH	Down switch input.
19	USER_LED	User LED signal.
20	/RESET	RESET signal only for controller on daughter board and 3-phase bridge driver. *

\* JM60 reset signal is connected only on BDM connector J9.

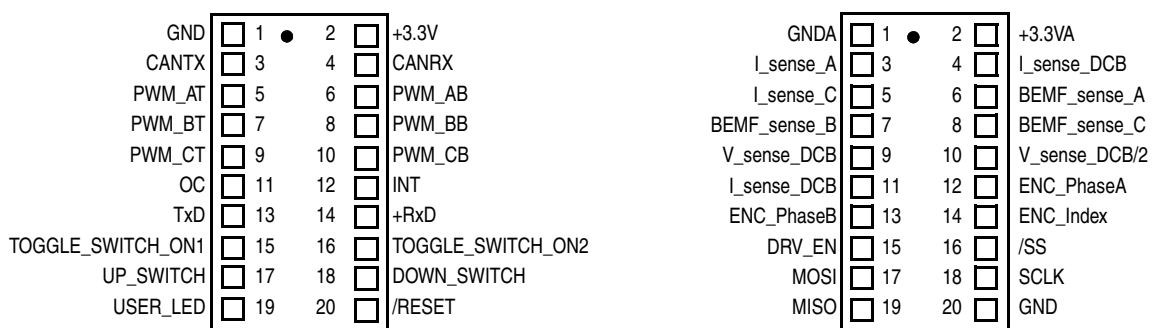
**Table 3-5 Daughter Board Connector J8 — Signal Descriptions**

Pin #	Signal Name	Description
1	GNDA	Analog power supply ground.
2	+3.3VA	Analog +3.3 V power supply.
3	I_sense_A	Analog sense signal that measures the current in phase A. It is scaled at 50 V per A of DC-bus current.
4	I_sense_B	Analog sense that measures the current in phase B. It is scaled at 0.563 V per A of DC-bus current.
5	I_sense_C	Analog sense signal that measures the current in phase C. It is scaled at 0.563 V per A of DC-bus current.
6	BEMF_sense_A	Analog sense signal that measures phase A back EMF. It is scaled at 8.09 mV per V of DC-bus voltage.
7	BEMF_sense_B	Analog sense signal that measures phase B back EMF. It is scaled at 8.09 mV per V of DC-bus voltage.
8	BEMF_sense_C	Analog sense signal that measures phase C back EMF. It is scaled at 8.09 mV per V of DC-bus voltage.



**Table 3-5 Daughter Board Connector J8 — Signal Descriptions (Continued)**

Pin #	Signal Name	Description
9	V_sense_DCB	Analog sense signal that measures bus voltage. It is scaled at 8.09 V per V of DC-bus voltage.
10	V_sense_DCB/2	Analog sense signal that measures bus voltage. It is scaled at 8.09 V per V of DC-bus voltage.
11	I_sense_DCB	Analog sense signal that measures bus current. It is scaled at 8.09 V per A of DC-bus current.
12	ENC_PhaseA	Encoder or hall sensor phase A input pin logic.
13	ENC_PhaseB	Encoder or hall sensor phase B input pin logic.
14	ENC_Index	Encoder index or hall sensor phase C input pin logic.
15	DRV_EN	3-phase bridge-gate driver enable signal.
16	/SS	SPI pin chip select pin for 3-phase bridge driver.
17	MOSI	SPI pin master out slave in pin for 3-phase bridge driver.
18	SCLK	SPI pin clock source pin input for 3-phase bridge driver.
19	MISO	SPI pin master in slave out pin for 3-phase bridge driver.
20	GND	Digital and power ground.

**Figure 3-1 J7 and J8 Connector Physical View**

### 3.2.6 USB Controller BDM Header J9

It serves for updating the software for JM60. Signals are described in [Table 3-6](#). The BDM header J9 is not populated.

**Table 3-6 USB Controller BDM Header J9 — Signal Descriptions**

Pin #	Signal Name	Description
1	BKGD/MS	Background debug pin
2	GND	Digital ground
3	No Connect	
4	/RESET_JM	$\overline{\text{RESET}}$ signal
5	No Connect	
6	+3.3V	Digital +3.3 V power supply

### 3.2.7 USB Connector J10

USB connector J10 serves for connecting the controller to the host PC via a virtual serial port. Signals are described in [Table 3-7](#).

**Table 3-7 USB Connector J10 — Signal Descriptions**

Pin #	Signal Name	Description
1	No Connect	
2	UDSBDN	Negative USB differential signal
3	UDSBDP	Positive USB differential signal
4	GND	Digital ground

# Chapter 4

## Design Consideration

### 4.1 Overview

The 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive is designed for software development. In addition to the hardware needed to run a motor, a variety of feedback signals that facilitate control-algorithm development are provided. A set of schematics for the drive appears in the following section.

Circuit descriptions for the drive appear in [4.2 3-Phase Bridge](#) through [4.12 Control Switches](#). One phase leg of the 3-phase bridge is examined in [4.2 3-Phase Bridge](#). Bus voltage and bus current feedback are discussed in [4.3 Bus Voltage and Current Feedback](#). Safety functions are highlighted in [4.4 Overcurrent, Undervoltage, and Other Safety Functions](#). Back-EMF signals appear in [4.5 Back EMF Signals](#). Phase current sensing is discussed in [4.6 Phase Current Sensing](#). The test points description and LED description are in [4.7 Test Points and LED Indication](#), all power supplies and voltage reference are described in [4.8 Power Supplies and Voltage Reference](#). Encoder circuitry is described in [4.9 Encoder/Hall-Effect Interface](#). The CAN physical layer interface is discussed in [4.10 CAN Interface](#). The USB interface appears in section [4.11 USB/SCI Bridge](#) and finally, push-buttons and the toggle switch are described in [4.12 Control Switches](#).

### 4.2 3-Phase Bridge

The output stage is configured as a 3-phase bridge with MOSFET output transistors. It is simplified considerably by an integrated gate driver that has an overcurrent, undervoltage, and other safety features. [Figure 4-1](#) shows a schematic of one phase. At the input, pull-down resistor R99 sets a logic low in the absence of a signal for the low side transistor. Open input pull-down is important, because the power transistors must stay off in the case of a broken connection or an absence of power on the daughter board. Gate-driver inputs are 3 V compatible. A Freescale device, the MC33927, supplies the gate drive. The MC33927 also provides undervoltage hold-off and overcurrent. Undervoltage hold-off threshold value is 8 V. The MC33927 has an implemented dead time insertion, which can be configured using SPI. The default dead time value is typically 15  $\mu$ s. Current limiting and undervoltage hold-off are discussed further in [4.4 Overcurrent, Undervoltage, and Other Safety Functions](#). One important design decision in a motor drive is the selection of gate-drive impedance for the output transistors. In [Figure 4-1](#), resistor R69, R70, diode D11, and the MC33927 nominal 100 mA current-sinking capability determine gate-drive impedance for the lower half-bridge transistor. A similar network is used on the upper half-bridge. These networks set the turn-on gate-drive impedance at approximately 100  $\Omega$  and the turn-off gate drive to approximately 100 mA. These values produce transition times of approximately 285 ns.

Transition times of this length represent a carefully weighed compromise between power dissipation and noise generation. Generally, transition times longer than 250 ns tend to get power hungry at non-audible

### 3-Phase Bridge

PWM rates; transition times under 50 ns create  $di/dt$ s so large that proper operation is difficult to achieve. The BLDC Motor Control Drive is designed with switching times at the higher end of this range to minimize noise.

Anti-parallel diode softness is also a primary design consideration. If the anti-parallel diodes in an off-line motor drive are allowed to snap, the resulting  $di/dt$ s can cause noise management problems, difficult to solve. In general, the peak to zero  $di/dt$  should be approximately equal to the  $di/dt$  applied to turning off the anti-parallel diodes. The FDS3672 MOSFETs used in this design are targeted at this kind of reverse recovery.



### 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive, Rev. 0

### 4.3 Bus Voltage and Current Feedback

Figure 4-2 shows the circuitry that provides feedback signals proportional to bus voltage and bus current. Bus voltage is scaled down by a voltage divider consisting of R23, R27, and R104. The values are chosen in such way that a 36.3 V bus voltage corresponds to 3.3 V at output V\_sense\_DCB. The V\_dcb is scaled at 91 mV per V of the DC-bus voltage, and is connected to the daughter board connector J8 pin 9 V\_sense\_DCB. An additional output, V\_sense\_DCB/2, provides a reference used in zero-crossing detection. The V\_dcb/2 is scaled at 45.5 mV per V of the DC-bus voltage, and is connected to the daughter board connector J8 pin 10 V\_sense\_DCB/2.

Bus current is sampled by resistor R88 in Figure A-9, and amplified in the MC33927's operational amplifier (Figure 4-2). This circuit provides a voltage output suitable for sampling on A/D (analog-to-digital) inputs. The MC33927's operational amplifier is used as a differential amplifier for bus-current sensing. With  $R82 = R83$ ,  $R102 = R103$ , and  $R81 = R84$ , the gain is given by:

$$A = R81 / (R82 + R102) \quad (\text{EQ 4-1})$$

The output voltage is shifted up by +1.65 V\_REF to accommodate positive and negative current swings. A  $\pm 400$  mV voltage drop across the sense resistor corresponds to a measured current range of  $\pm 4$  A. The AMP\_OUT signal is internally connected to the overcurrent comparator of the MC33927, and provides an overcurrent triggering function. A discussion about overcurrent limiting follows in chapter 4.4 [Overcurrent, Undervoltage, and Other Safety Functions](#). In addition, the AMP\_OUT is connected to the daughter board connector J8 pin 11 I\_sense\_DCB.

The shunt resistor is represented by a 0.1  $\Omega$  resistance Welwyn SMD precision resistor, the same as the phase-current measurement resistors.

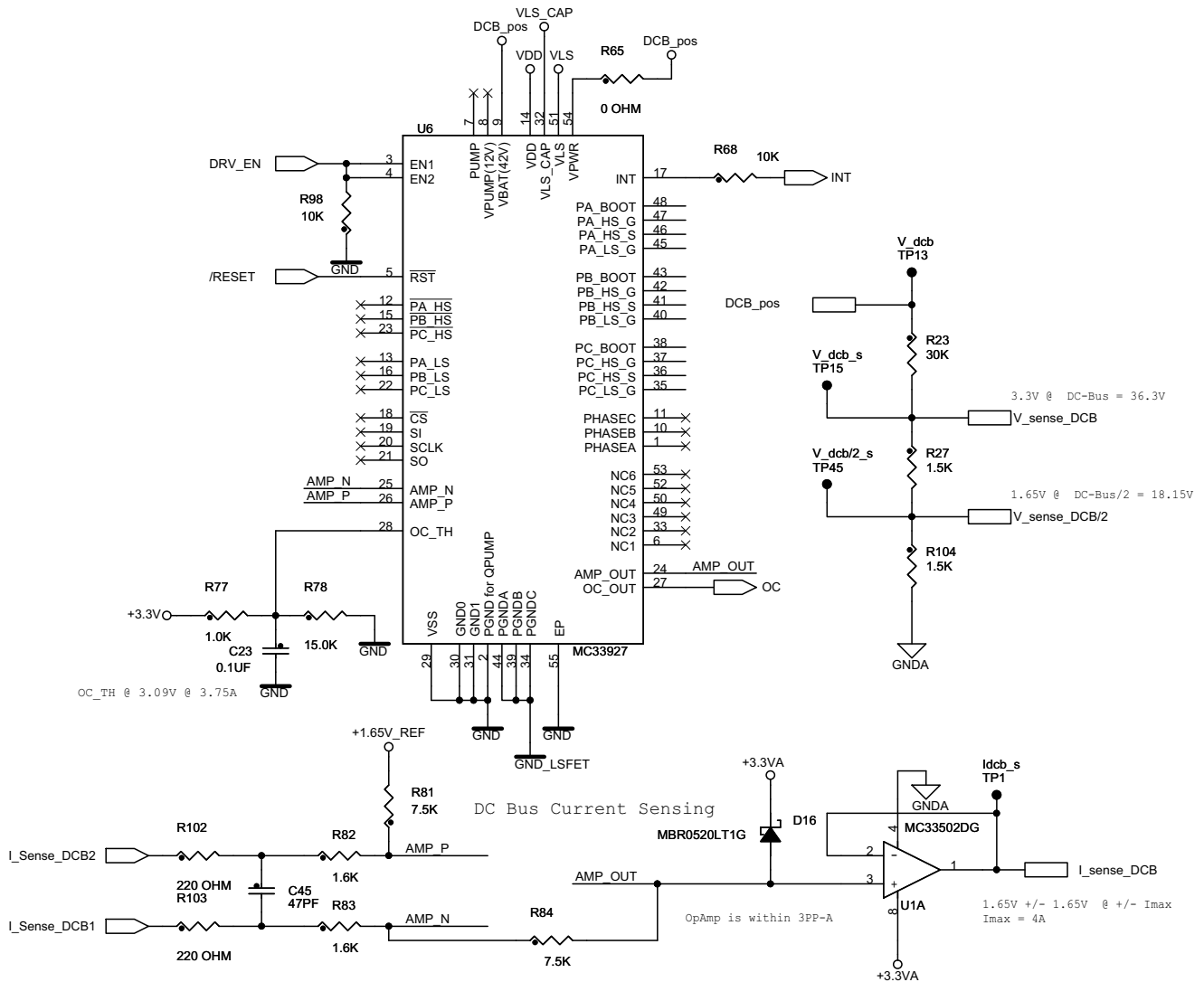


Figure 4-2 Bus Feedback

## 4.4 Overcurrent, Undervoltage, and Other Safety Functions

The MC33927 provides overcurrent and undervoltage functions (Figure 4-2). Bus current feedback is filtered to remove spikes, and this signal is fed into the MC33927 current comparator. Therefore, when bus current exceeds 3.75 A, all six output transistors are switched off. Once a fault state has been detected, all six gate drivers are off, until the fault state is cleared by the low-level on  $\overline{\text{RESET}}$  pin, or by switching the board off. Then you can switch the power stage on.

The undervoltage function is implemented internally. The MC33927's supply voltage is sensed internally. If this voltage is lower than 8 V, the hold-off circuit is evaluated, and an interrupt is generated if set.

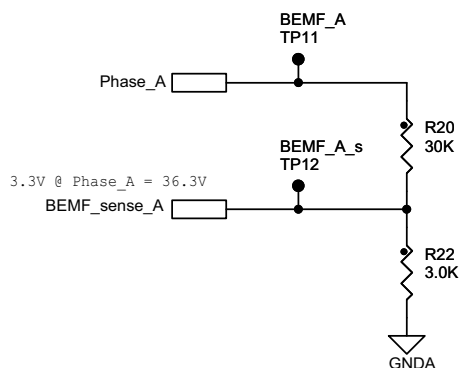
The MC33927 safety functions keep the driver operating properly and within safe limits. Current limiting by itself, however, does not necessarily ensure that a board is operating within safe thermal limits. The MC33927 has a thermal warning feature. If the temperature rises above 170 °C on one of the three detectors, then an interrupt is generated if set.

The MC33927 driver has also other safety features such as desaturation detection, phase error, framing error, write error after the lock, and exiting **RESET**. All these features can be configured through SPI to trigger interrupts. Detailed information is available in the driver datasheet.

## 4.5 Back EMF Signals

Back EMF signals are included to support sensorless algorithms for BLDC motors, and dead time distortion correction for sinusoidal motors. Referring to [Figure 4-3](#), which shows circuitry for phase A, the raw phase voltage is scaled down by a voltage divider consisting of R20 and R22. Output from this divider produces back EMF sense voltage BEMF\_sense\_A. Resistor values are chosen such that a 36.3 V of phase voltage corresponds to a 3.3 V A/D input. The BEMF\_sense\_A is led directly to the daughter board connector J8 pin 6, without any offset correction (see [Figure A-6](#)).

The V\_sense\_DCB and V\_sense\_DCB/2 are provided by the R23, R27, and R104 resistor divider from the bus voltage (see [Figure 4-2](#)).



**Figure 4-3 Back EMF Sensing — Phase A**

## 4.6 Phase Current Sensing

Sampling resistors provide phase current information for all three phases. Because these resistors sample the current in the lower phase legs, they do not directly measure the phase current. However, given phase voltages for all three phases, phase current can be constructed mathematically from the lower phase leg values. The measurement circuitry for one phase is shown in [Figure 4-4](#). Referencing the sampling resistors to the negative motor rail makes the measurement circuitry straightforward and inexpensive. Current is sampled by resistor R85 and amplified by the differential amplifier U1B.

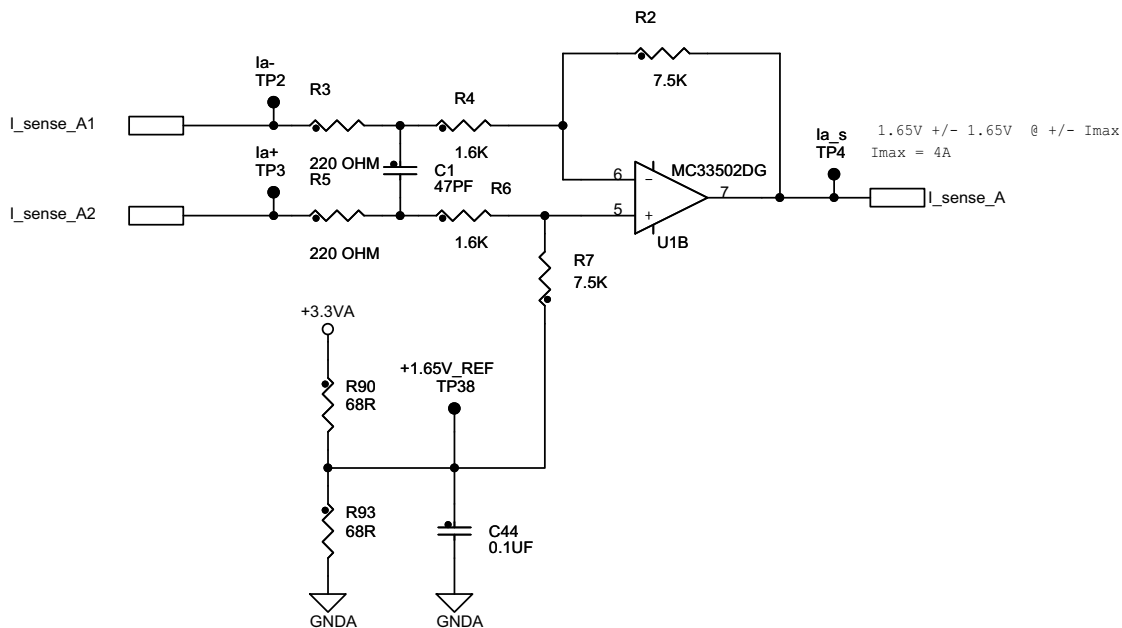


This circuit provides a voltage output suitable for sampling on A/D inputs. The MC33502DG is used as a differential amplifier. With  $R2 = R7$ ,  $R3 = R5$ , and  $R4 = R6$ , the gain is given by:

$$A = R2 / (R3 + R4) \quad (\text{EQ 4-2})$$

The input voltage is shifted up by +1.65 V<sub>REF</sub> to accommodate both positive and negative current swings. A  $\pm 400$  mV voltage drop across the shunt resistor corresponds to a measured current range of  $\pm 4$  A. As a source for +1.65 V<sub>REF</sub>, we use the voltage divider described in chapter 4.8.5 +1.65 V Reference.

The gain of this operational amplifier is 4.12 with the +1.65 V offset, in other words the output  $\pm 1.65$  V corresponds to  $\pm 4$  A. The output is connected to the daughter board connector J8.



**Figure 4-4 Phase Current Sensing**

## 4.7 Test Points and LED Indication

Some voltages and currents of the 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive can be sensed, whilst some are connected to the daughter board connector pins. Those are: back-EMF voltage, phase current, bus-power voltage, half of bus-power voltage, bus current, PWM signal for all six switches of the 3-phase power bridge, and other control signals.

The four test points are located near the corners of the board and provide a GND signal (digital ground) for easy oscilloscope attachment. As mentioned in previous chapters, the board contains more grounds — analog and digital.

The 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive contains 45 round-shape test points to allow the user to easily check the voltage of all important points:

- **TP1 Idcb\_s** — Bus-current output test point, scaled at 0.413 V per A of bus current B, and shifted by 1.65 V.
- **TP2 Ia-** — Phase A current sense resistor test point for node I\_sense\_A1.
- **TP3 Ia+** — Phase A current sense resistor test point for node I\_sense\_A2.
- **TP4 Ia\_s** — Phase A current output test point for node I\_sense\_A, scaled at 0.413 V per A of phase current A, and shifted by 1.65 V.
- **TP5 Ib-** — Phase B current sense resistor test point for node I\_sense\_B1.
- **TP6 Ib+** — Phase B current sense resistor test point for node I\_sense\_B2.
- **TP7 Ib\_s** — Phase B current output test point of node I\_sense\_B, scaled at 0.413 V per A of phase current B, and shifted by 1.65 V.
- **TP8 Ic-** — Phase C current sense resistor test point for node I\_sense\_C1.
- **TP9 Ic+** — Phase C current sense resistor test point for node I\_sense\_C2.
- **TP10 Ic\_s** — Phase C current output test point of node I\_sense\_C, scaled at 0.413 V per A of phase current C, and shifted by 1.65 V.
- **TP11 BEMF\_A** — Back EMF phase A test point.
- **TP12 BEMF\_A\_s** — Back EMF phase A test point, scaled at 91 mV per V of phase voltage A.
- **TP13 V\_dcb** — Bus voltage test point.
- **TP14 BEMF\_B** — Back EMF phase B test point.
- **TP15 V\_dcb\_s** — Bus voltage test point, scaled at 91 mV per V.
- **TP16 BEMF\_B\_s** — Back EMF phase B test point, scaled at 91 mV per V of phase voltage B.
- **TP17 BEMF\_C** — Back EMF phase C test point.
- **TP18 BEMF\_C\_s** — Back EMF phase C test point, scaled at 91 mV per V of phase voltage C.
- **TP19 CANTX** — TX signal for CAN physical layer.
- **TP20 CANRX** — RX signal for CAN physical layer.
- **TP21 TxD** — Tx signal for SCI communication between JM60 and daughter board controller.
- **TP22 RxD** — Rx signal for SCI communication between JM60 and daughter board controller.
- **TP23** — signal activity on Tx signal.
- **TP24** — signal activity on Rx signal.
- **TP25 PWM\_AT** — PWM control signal for top transistor gate of phase A, test point on connector J7 pin.
- **TP26 PWM\_AB** — PWM control signal for bottom transistor gate of phase A, test point on connector J7 pin.
- **TP27 PWM\_BB** — PWM control signal for bottom transistor gate of phase B, test point on connector J7 pin.

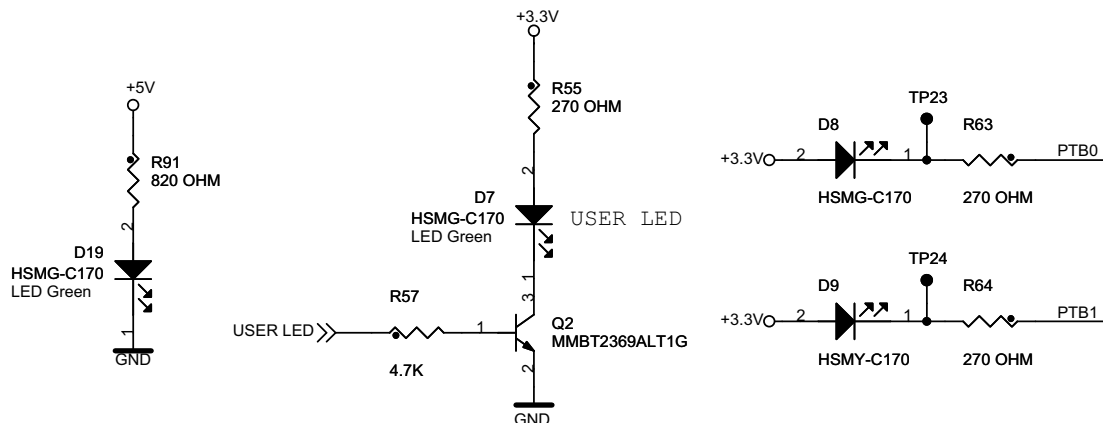
- **TP28 PWM\_CT** — PWM control signal for top transistor gate of phase C, test point on connector J7 pin.
- **TP29 PWM\_BT** — PWM control signal for top transistor gate of phase B, test point on connector J7 pin.
- **TP30 PWM\_CB** — PWM control signal for bottom transistor gate of phase C, test point on connector J7 pin.
- **TP31 /SS** — Chip-select signal for SPI communication.
- **TP32 MOSI** — MOSI signal for SPI communication.
- **TP33 SCLK** — Clock signal for SPI communication.
- **TP32 MISO** — MISO signal for SPI communication.
- **TP35 V\_dcb** — Bus-voltage test point.
- **TP36 +5V** — This point is the output of the U7 switching step-down inverter. It serves as the power supply for the on-board encoder and CAN physical layer interface.
- **TP37 +3.3V** — This point is the output of the U8 linear voltage regulator. It serves as the power supply for the on-board logic inverter and JM60 controller, and as the source for generating +3.3 VA. It is connected to the daughter board connector J7.
- **TP38 +1.65V\_REF** — Reference-voltage test point.
- **TP39 GND** — Ground test point.
- **TP40 GND** — Ground test point.
- **TP41 GND** — Ground test point.
- **TP42 GND** — Ground test point.
- **TP43 GNDA** — Analog ground test point.
- **TP44 GNDA** — Analog ground test point.
- **TP45 V\_dcb/2\_s** — Half of bus voltage test point, scaled at 45.5 mV per V.

This board also contains ten LEDs as indicators:

- **D1** — PWM\_AT indication LED, activated on low level.
- **D2** — PWM\_AB indication LED, activated on high level.
- **D3** — PWM\_BT indication LED, activated on low level.
- **D4** — PWM\_BB indication LED, activated on high level.
- **D5** — PWM\_CT indication LED, activated on low level.
- **D6** — PWM\_CB indication LED, activated on high level.
- **D7** — User LED diode for user-defined purposes, activated on high level.
- **D8** — Indicated communication activity on TxD pin.
- **D9** — Indicated communication activity on RxD pin.
- **D19** — Indicates that the +5 V level is properly generated.

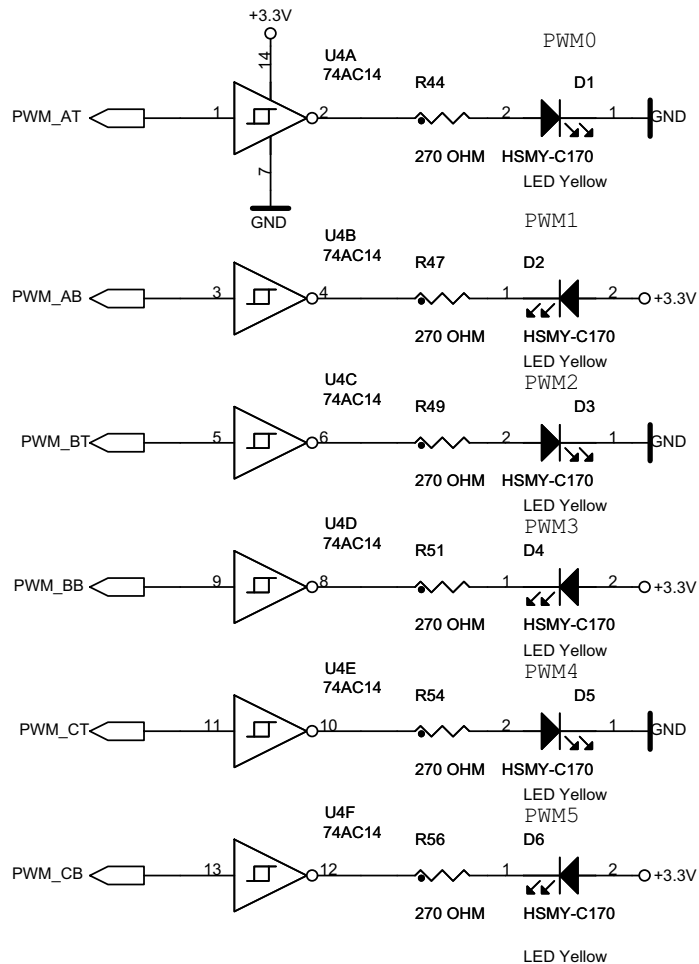
## Test Points and LED Indication

For more details, see [Figure 4-5](#).



**Figure 4-5 LED Indication**

For more details see [Figure 4-6](#).



**Figure 4-6 PWM LED Indication**

## 4.8 Power Supplies and Voltage Reference

The 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive contains devices that require various voltage levels of +5 V or +3.3 V.

### 4.8.1 Input Power Supply

The bus can be supplied from two input connectors, J2 and the J3 power jack. The power source should be able to deliver at least 4 A. The DC-bus has reverse polarity protection. The MC33927 driver is supplied directly from the DC-bus. The +5 V power supply is served from bus voltage.

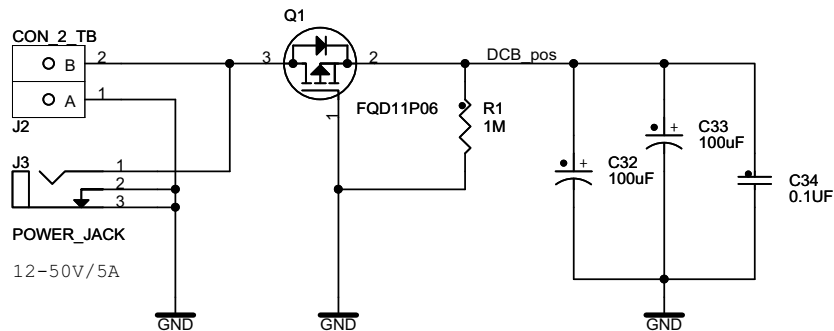


Figure 4-7 DC-Bus Input Circuitry

### 4.8.2 +5 V Power Supply

The +5 V level is generated by means of the LM2594HVM switching step-down regulator (see [Figure 4-8](#)), which generates this level from bus voltage. This converter can supply up to 500 mA. This voltage level serves the MC33269D linear regulator, encoder, and CAN physical layer interface. If the LM2594HVM converter operates properly, the D19 green LED is lit.

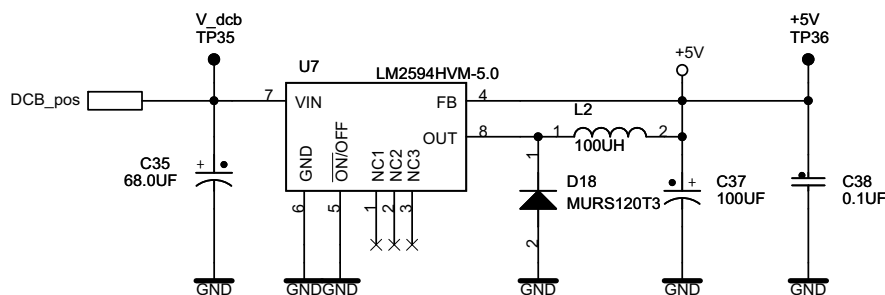


Figure 4-8 +5 V Power Supply

### 4.8.3 +3.3 V Power Supply

An important voltage level for this board is +3.3 V. This voltage level is obtained from the MC33269D linear voltage regulator, and can supply up to 800 mA (Figure 4-9). The +3.3 V level is used to supply the on-board logic inverter and JM60 controller. It is connected to the daughter board connector J7.

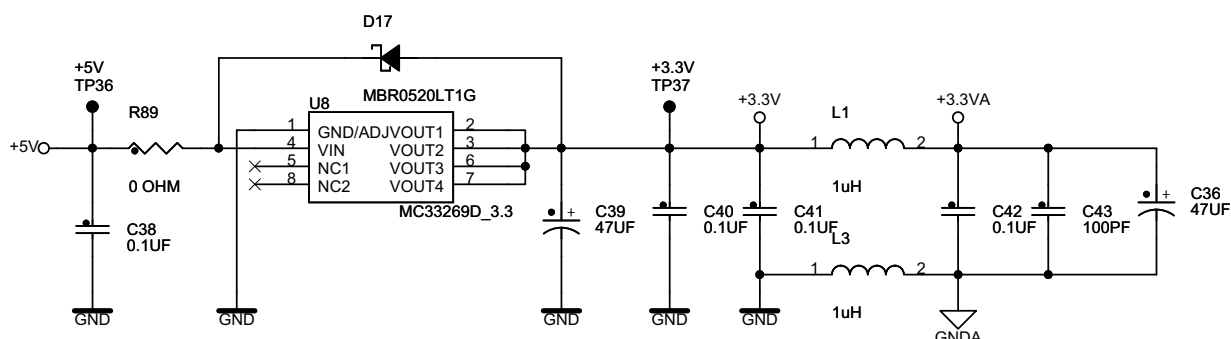


Figure 4-9 +3.3 VA / +5 VA Power Supply

### 4.8.4 +3.3 VA Power Supply

The +3.3 VA power supply is drawn from the +3.3 V level by passive filtering through L1 and L3 (see Figure 4-9). Maximum current load should not exceed 200 mA. This voltage level serves the on-board operational amplifiers and voltage reference. It is also connected to the daughter board connector J8.

### 4.8.5 +1.65 V Reference

The +1.65 V reference is generated from the +3.3 VA level simply by the voltage divider (see Figure 4-10). This reference serves to shift the DC-bus and phase-current-sensing values. It can sink up to 30 mA.

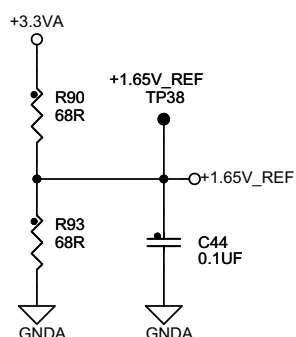
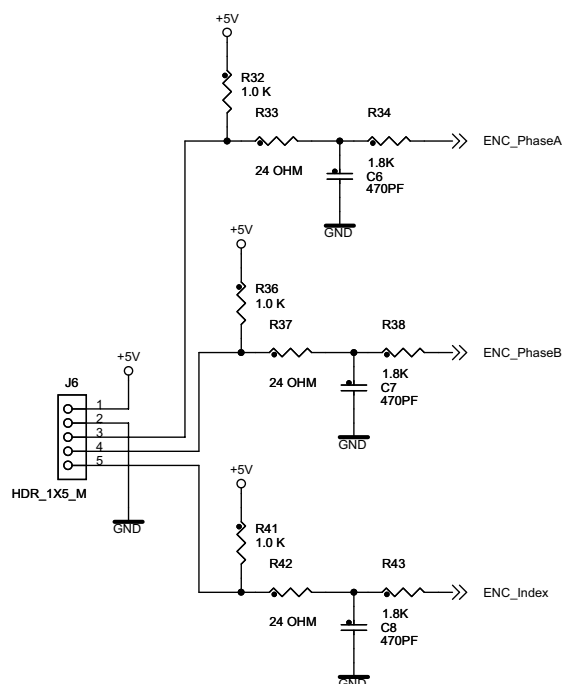


Figure 4-10 +1.65 V Reference Source

## 4.9 Encoder/Hall-Effect Interface

The 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive contains an encoder/hall-effect interface. The circuit is designed to accept +3.3 V to +5.0 V encoder or hall-effect sensor inputs. Input noise filtering is supplied on the input path for the encoder/hall-effect interface.

Filtered signals are then connected to the controller daughter board connector J8. [Figure 4-11](#) contains the encoder interface.



**Figure 4-11 Encoder/Hall-Effect Circuitry**

## 4.10 CAN Interface

The board contains a CAN interface. The main part of the interface is CAN controller PCA82C250. The PCA82C250 is the interface between the CAN communication controller and the physical bus. The device provides differential transmit capability to the bus and differential receive capability to the CAN controller. The CAN interface is compatible with ISO 11898, and allows a maximum data transfer rate of 1 Mbit/s. The CAN transceiver is short-circuit protected, transient-bus protected, thermal protected, RFI and EMI immunized.

The CAN transceiver is connected via CANTX and CANRX signals to the daughter board connector J7. Bus signals CANL and CANH are connected to the CAN bus header J4. Shorten the jumper terminal J5 to attach the bus' end termination resistor. This resistor ensures that data will not be reflected at the bus' end. The schematic diagram of the CAN is in [Figure 4-12](#).

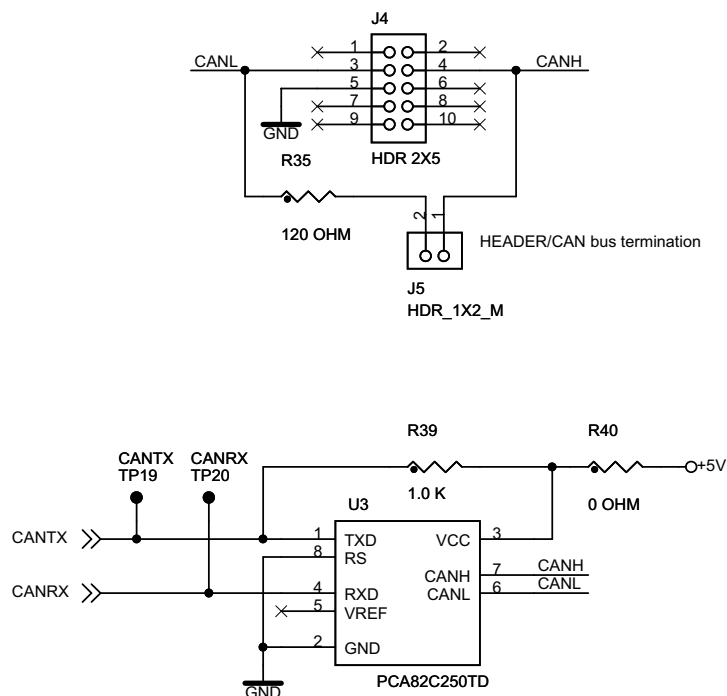


Figure 4-12 CAN Interface

## 4.11 USB/SCI Bridge

The 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive provides a USB interface by the use of USB level converter circuitry, referred to in the USB/SCI bridge schematic diagram in [Figure A-7](#). The core of the USB interface is the MC9S08JM60 controller and its universal serial bus (USB) device controller. The USB device controller module is based on the Universal Serial Bus Specification Rev 2.0, and provides a single-chip solution for full-speed (12 Mbps) USB device applications. The USB level converter transitions the SCI UART's +3.3 V signal levels to USB compatible signal levels, and connects to the host's serial port via the standard USB connector J10. The pinout of the USB connector is listed in [Table 3-7](#). To enable proper working of the serial interface, code for the USB/SCI bridge should be loaded in the JM60 controller. LED diodes D8 and D9 indicate communication activity.

## 4.12 Control Switches

Three on-board push-button switches and one toggle switch are provided for the user's program control (see [Figure 4-13](#)). Two push-buttons (up, down) are directly connected to the daughter board connector J7. One push-button ( $\overline{\text{RESET}}$ ) is provided for setting the daughter board controller  $\overline{\text{RESET}}$  input pin to logic level low. The  $\overline{\text{RESET}}$  signal is connected to the 3-phase driver and to the daughter board connector J7. A toggle switch is connected to the daughter board connector J7 too. This toggle switch has 3 stable positions — two on states in edge positions, and one off state in the middle position.



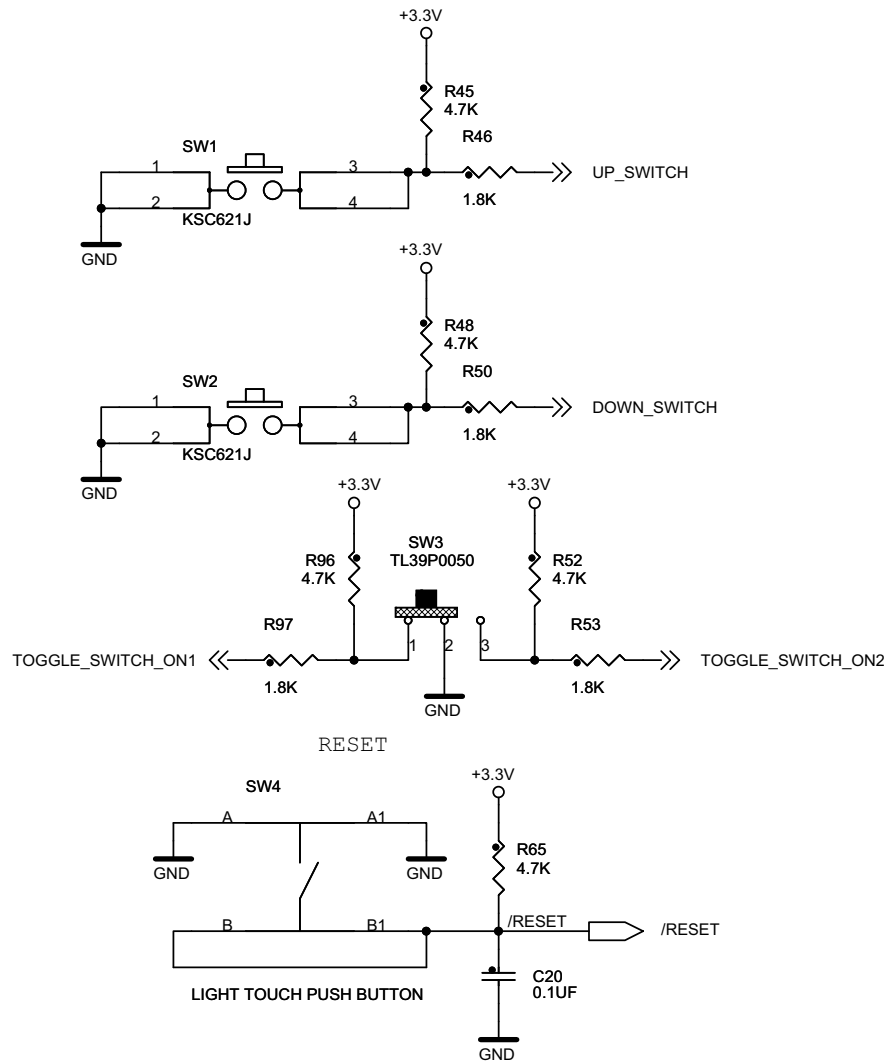


Figure 4-13 Control Switches





## **Appendix A.**

### **3-Phase BLDC/PMSM Motor Control Drive Schematics**

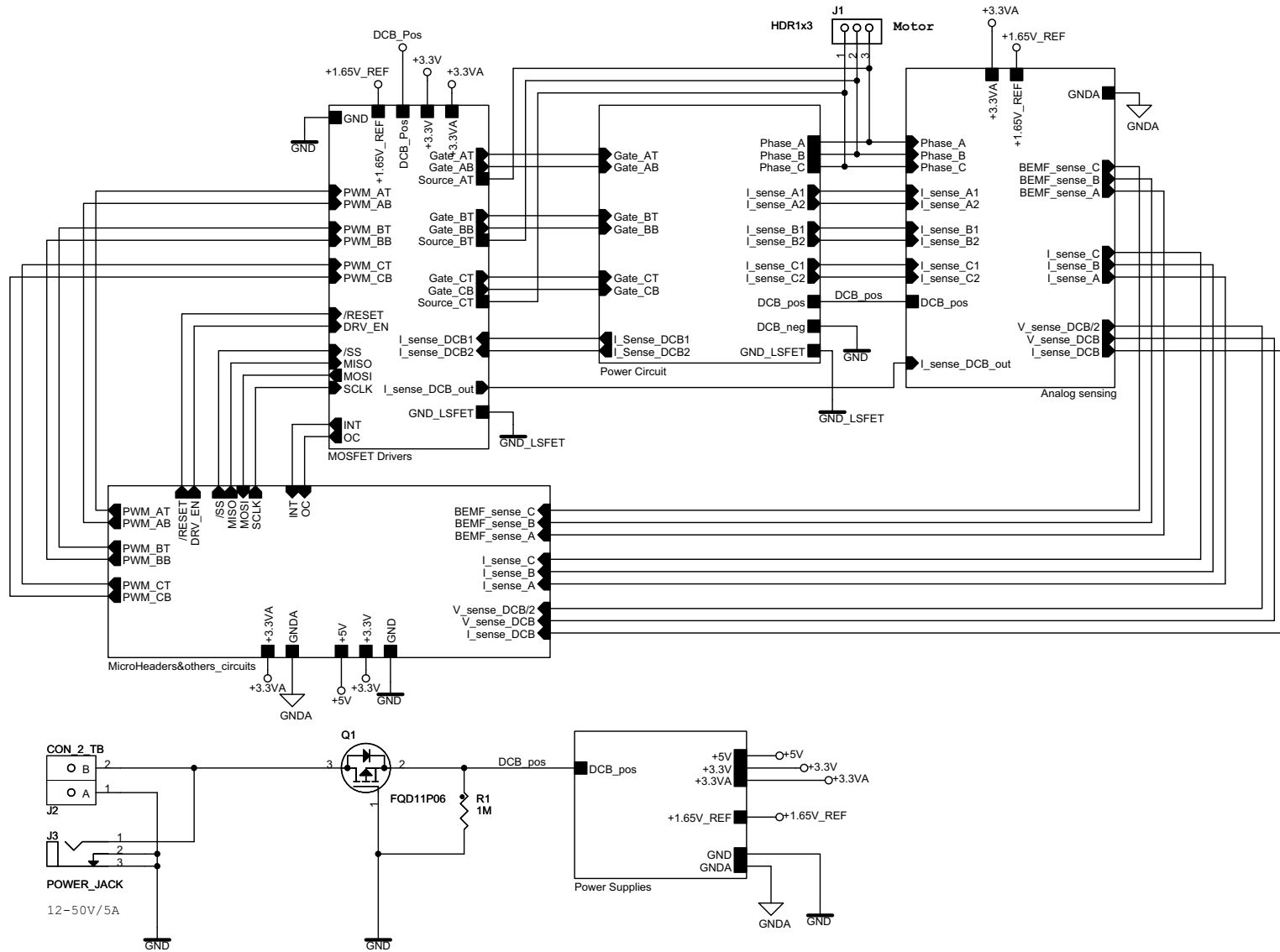


Figure A-1 Board Overview

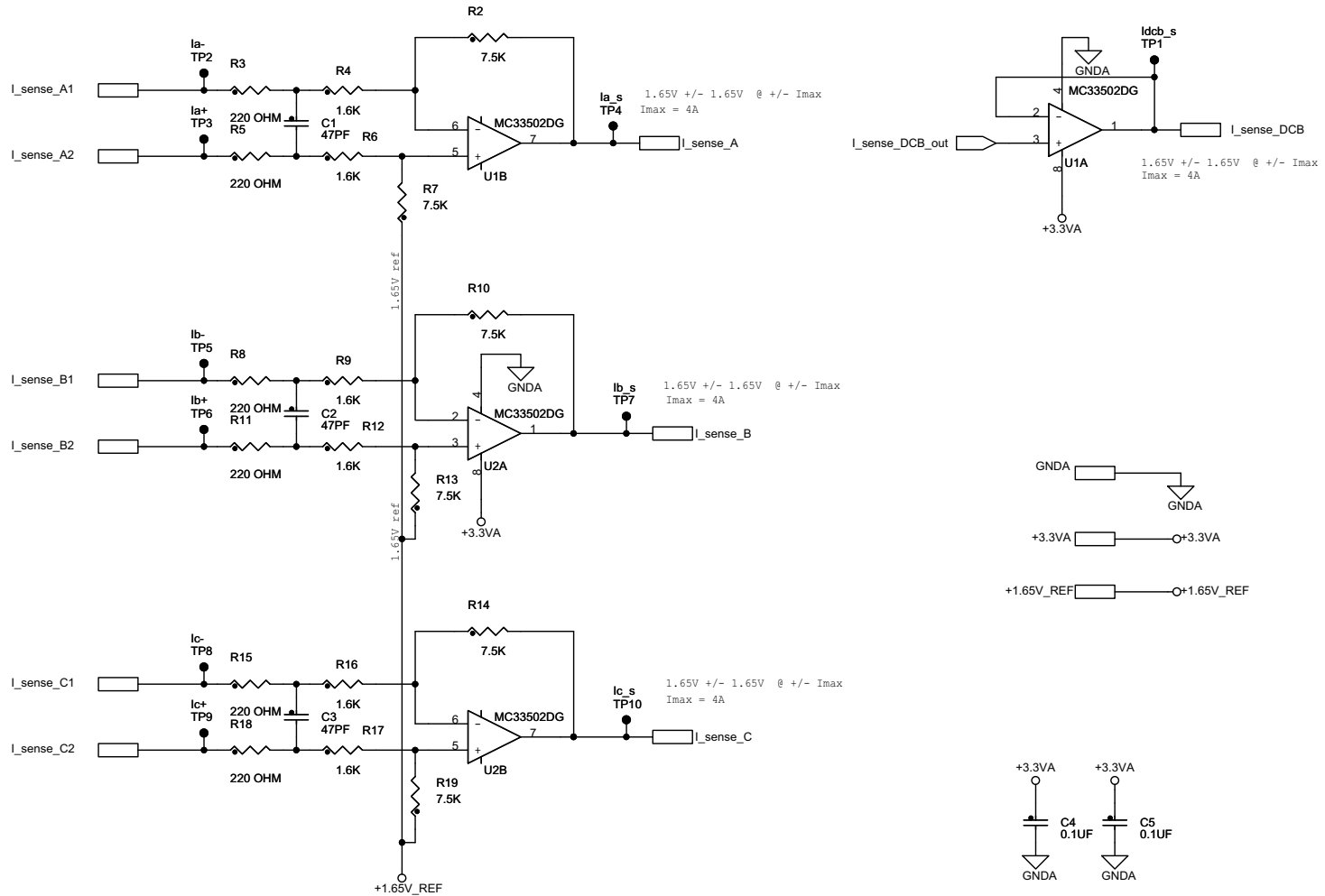


Figure A-2 Analog Sensing — Phase Current Sensing

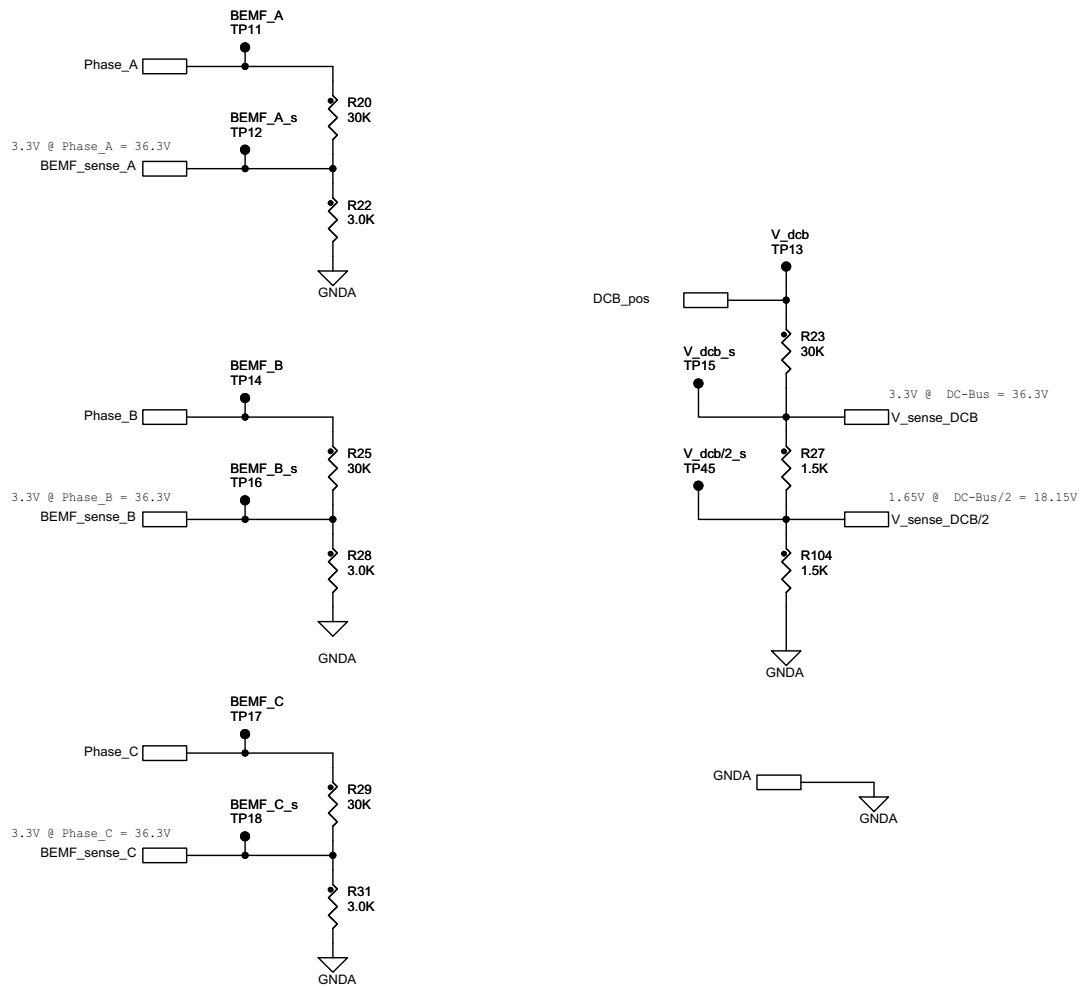


Figure A-3 Analog Sensing — Back EMF Sensing

3-Phase BLDC/PMSM Low-Voltage Motor Control Drive, Rev. 0

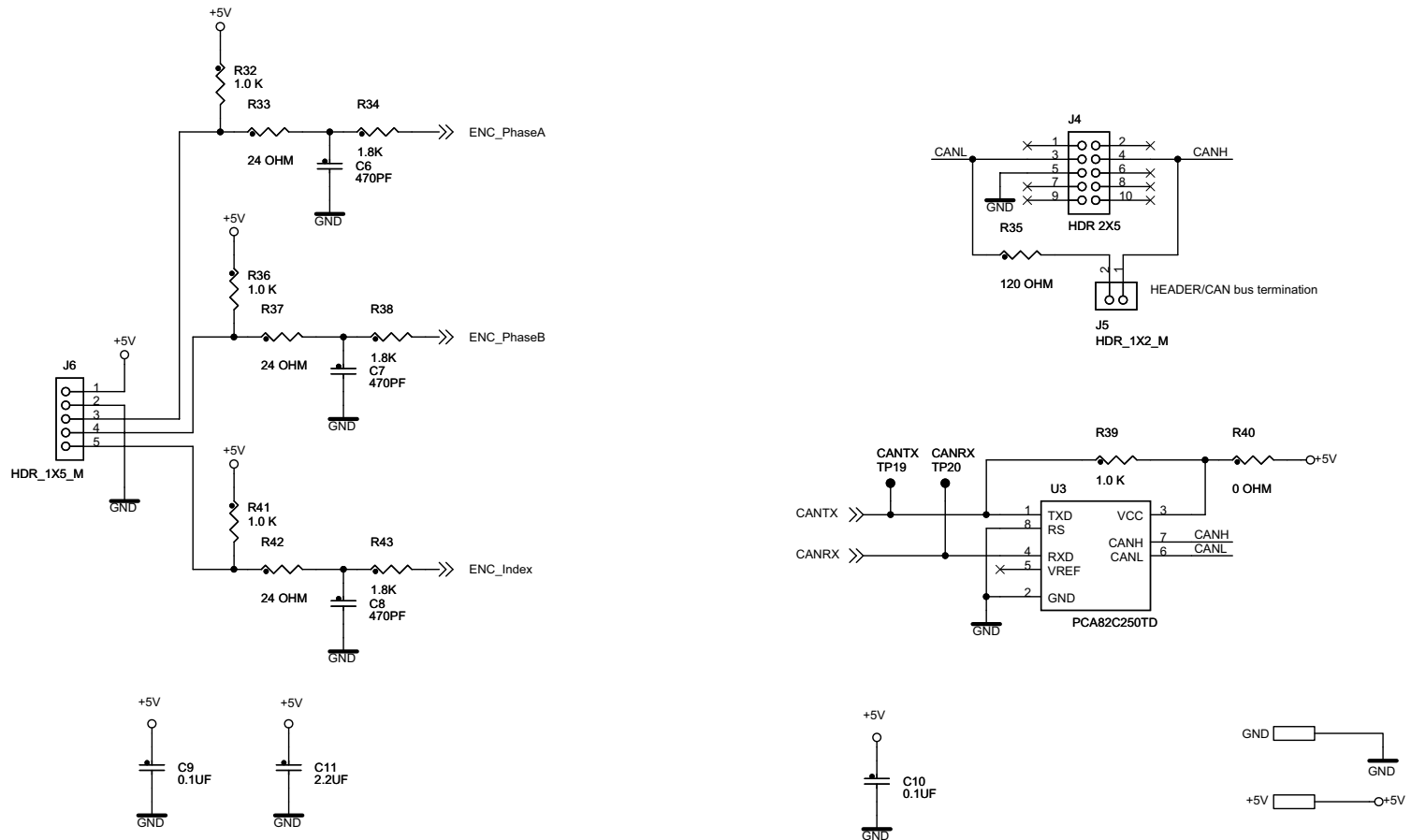
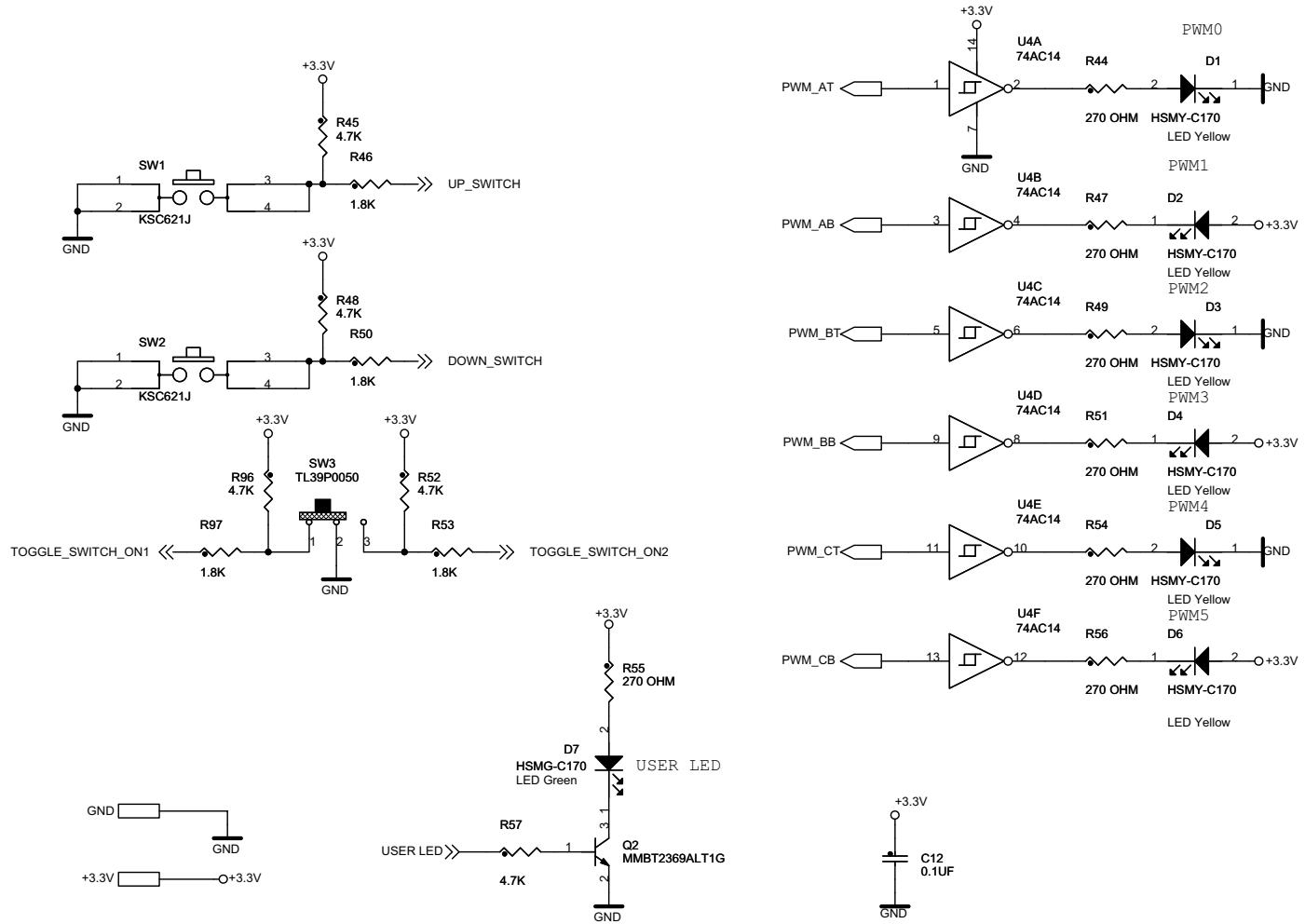


Figure A-4 Micro Headers & Other Circuits — Encoder/Hall Sensor & CAN



### Figure A-5 Micro Headers & Other Circuits — Switches, User, and PWM LEDs



3-Phase BLD/MSM Low-Voltage Motor Control Drive, Rev. 0

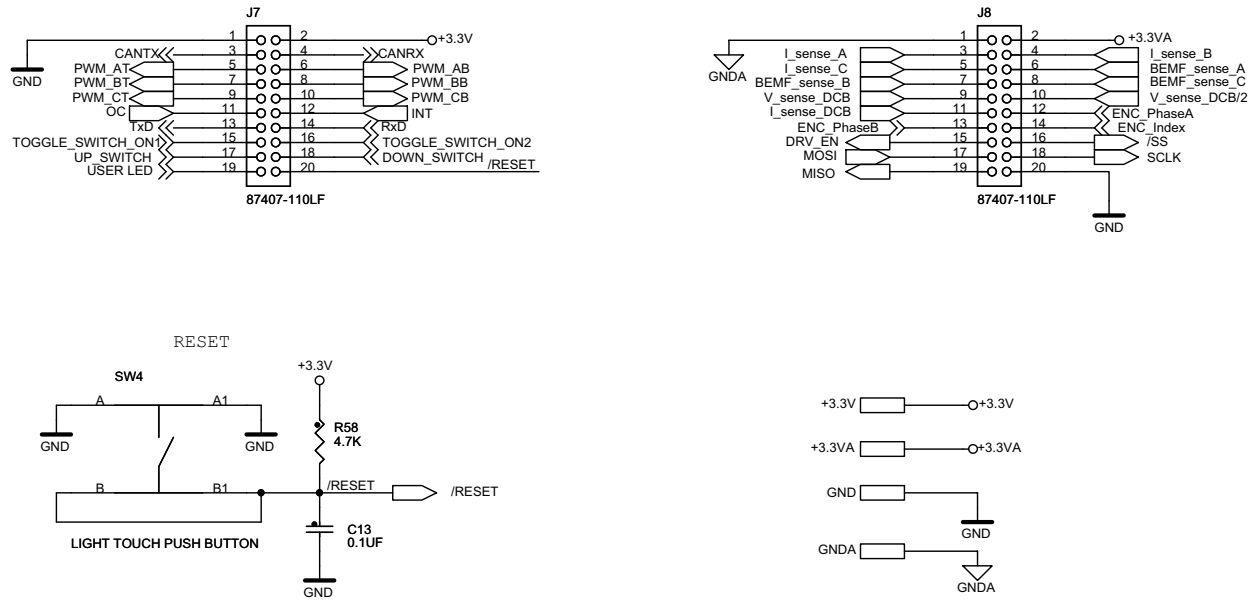


Figure A-6 Micro Headers & Other Circuits — Daughter Board Connectors & RESET

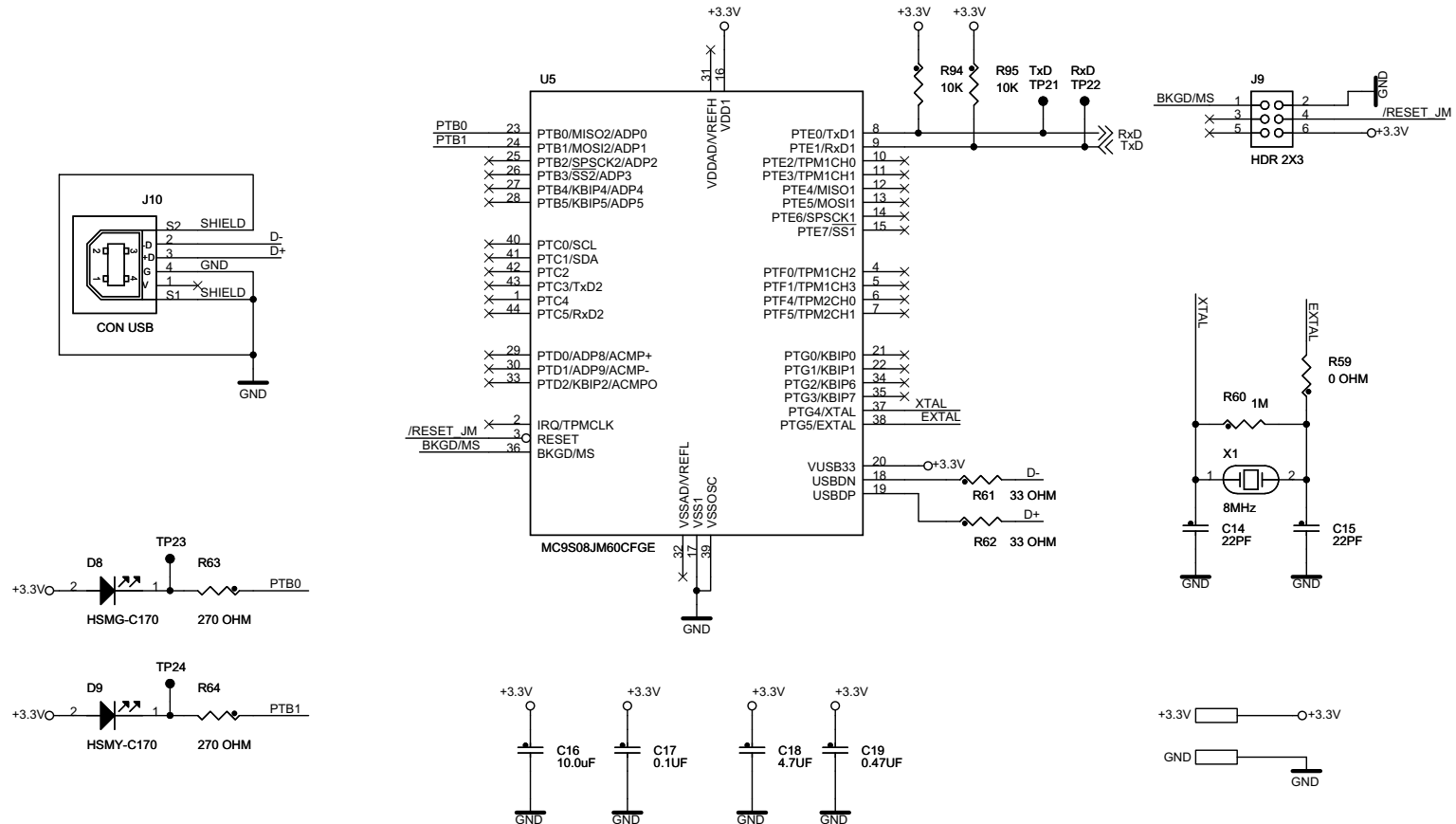


Figure A-7 Micro Headers &amp; Other Circuits — USB/SCI Bridge









## Appendix B. Bill of Materials

**Table B-1 Parts List**

DESIGNATORS	QUANTITY	DESCRIPTION	MANUFACTURER	PART NUMBER
C1-3,C5	4	47 pF / 100 V size 0805	ANY ACCEPTABLE	—
C4,C5,C9,C10,C12,C13,C17,C23,C27,C29,C31,C38,C40-C42,C44	16	100 nF / 100 V size 0805	ANY ACCEPTABLE	—
C6-C8	3	470 pF / 100 V size 0805	ANY ACCEPTABLE	—
C11,C26,C28,C30	4	2.2 $\mu$ F / 25 V size 0805	ANY ACCEPTABLE	—
C14,C15	2	22 pF / 100 V size 0805	ANY ACCEPTABLE	—
C16	1	10 $\mu$ F / 16 V size 0805	ANY ACCEPTABLE	—
C18	1	4.7 $\mu$ F / 16 V size 0805	ANY ACCEPTABLE	—
C19	1	470 nF / 25 V size 0805	ANY ACCEPTABLE	—
C20-C22	3	1 $\mu$ F / 25 V size 0805	ANY ACCEPTABLE	—
C24	1	2.2 $\mu$ F / 50 V size 1210	ANY ACCEPTABLE	—
C25,C34	2	100 nF / 100 V size 1206	ANY ACCEPTABLE	—
C32,C33	2	100 $\mu$ F / 80 V size H13	ANY ACCEPTABLE	—
C35	1	68 $\mu$ F / 100 V size H13	ANY ACCEPTABLE	—
C36,C39	2	47 $\mu$ F / 6.3 V size C	ANY ACCEPTABLE	—
C37	1	100 $\mu$ F / 16 V size E	ANY ACCEPTABLE	—
C43	1	100 pF / 100 V size 0805	ANY ACCEPTABLE	—
D1-D6,D9	7	Yellow Display LED size 0805	AVAGO TECHNOLOGIES	HSMY-C170
D7,D8,D19	8	Green Display LED size 0805	AVAGO TECHNOLOGIES	HSMG-C170
D10-D17	8	0.5 A / 20 V Schottky Rectifier size SOD-123	ON SEMICONDUCTOR	MBR0520LT1G
D18	1	1 A / 200 V Ultrafast Rectifier size B	ON SEMICONDUCTOR	MURS120T3G
J1	1	HDR 1x3	MOLEX	09-65-2038
J2	1	CON_2_TB	LUMBERG INC	KRM 02
J3	1	Power Jack	SWITCHCRAFT	RAPC712X
J4	1	HDR 2x5	TYCO ELECTRONICS	4-103322-2
J5	1	HDR 1X2	TYCO ELECTRONICS	4-103321-8
J6	1	HDR 1X5	MOLEX	22-27-2051
J7,J8	2	87407-110	FCI	87407-110LF
J9	1	HDR 2X3	TYCO ELECTRONICS	4-103322-2
J10	1	CON USB	TYCO ELECTRONICS	292304-1
L1,L3	2	1 $\mu$ H size 2012	TDK	MLZ2012A1R0P
L2	1	100 $\mu$ H	Wurth Elektronik	744778920
Q1	1	9.4 A / 60 V MOSFET size D-PAK	FAIRCHILD SEMICONDUCTOR	FQD11P06TF

**Table B-1 Parts List**

DESIGNATORS	QUANTITY	DESCRIPTION	MANUFACTURER	PART NUMBER
Q2	1	200 mA / 40 V NPN size SOT-23	ON SEMICONDUCTOR	MMBT2369ALT1G
Q3-Q8	6	7.5 A / 100 V MOSFET size SOIC-8	FAIRCHILD SEMICONDUCTOR	FDS3672
R1,R60	2	1 M $\Omega$ Resistor 1/8 W 1 % size 0805	ANY ACCEPTABLE	—
R2,R7,R10,R13,R14,R19,R81,R84	8	7.5 k $\Omega$ Resistor 1/8 W 1 % size 0805	ANY ACCEPTABLE	—
R3,R5,R8,R11,R15,R18,R102,R103	8	220 $\Omega$ Resistor 1/8 W 1 % size 0805	ANY ACCEPTABLE	—
R4,R6,R9,R12,R16,R17,R82,R83	8	1.6 k $\Omega$ Resistor 1/8 W 1 % size 0805	ANY ACCEPTABLE	—
R20,R23,R25,R29	4	30 k $\Omega$ Resistor 1/8 W 1 % size 0805	ANY ACCEPTABLE	—
R22,R28,R31	3	3 k $\Omega$ Resistor 1/8 W 1 % size 0805	ANY ACCEPTABLE	—
R27,R104	21	1.5 k $\Omega$ Resistor 1/8 W 1 % size 0805	ANY ACCEPTABLE	—
R32,R36,R39,R41	41	1 k $\Omega$ Resistor 1/8 W size 0805	ANY ACCEPTABLE	—
R33,R37,R42	3	24 $\Omega$ Resistor 1/80 W size 0805	ANY ACCEPTABLE	—
R34,R38,R43,R46,R50,R53,R97	7	1.8 k $\Omega$ Resistor 1/8 W size 0805	ANY ACCEPTABLE	—
R35	1	120 $\Omega$ Resistor 1/8 W size 0805	ANY ACCEPTABLE	—
R40,R59,R65,R89	4	0 $\Omega$ Resistor 1/8 W size 0805	ANY ACCEPTABLE	—
R44,R47,R49,R51,R54-R56,R63,R64	9	270 $\Omega$ Resistor 1/80 W size 0805	ANY ACCEPTABLE	—
R45,R48,R52,R57,R58,R96	6	4.7 k $\Omega$ Resistor 1/8 W size 0805	ANY ACCEPTABLE	—
R61,R62	2	33 $\Omega$ Resistor 1/8 W size 0805	ANY ACCEPTABLE	—
R66,R67,R69-R76,R79,R80	12	10 $\Omega$ Resistor 1/8 W size 0805	ANY ACCEPTABLE	—
R68,R94,R95,R98-R101	7	10 k $\Omega$ Resistor 1/8 W size 0805	ANY ACCEPTABLE	—
R77	1	1 k $\Omega$ Resistor 1/8 W 1 % size 0805	ANY ACCEPTABLE	—
R78	1	15 k $\Omega$ Resistor 1/8 W 1 % size 0805	ANY ACCEPTABLE	—
R85-R88	4	100 m $\Omega$ Resistor 1 % size 2512	WELWYN COMPONENTS LIMITED	LR2512-R10FW
R90,R93	2	68 $\Omega$ Resistor 1/8 W 1 % size 0805	ANY ACCEPTABLE	—
R91	1	820 $\Omega$ Resistor 1/8 W size 0805	ANY ACCEPTABLE	—
SW1,SW2	2	20 mA / 32 V Touch Key	C&K COMPONENTS	KSC621J LFS
SW3	1	20 mA / 20 V Toggle Switch/3-state	APEM COMPONENTS	TL39P0050
SW4	1	20 mA / 32 V Touch Key	C&K COMPONENTS	KSC341J LFS
TP1-TP45	45	N/P	—	—
U1,U2	2	Operational Amplifier / SOIC-8	ON SEMICONDUCTOR	MC33502DR2G



**Table B-1 Parts List**

DESIGNATORS	QUANTITY	DESCRIPTION	MANUFACTURER	PART NUMBER
U3	1	CAN INTERFACE / SOIC-8	PHILIPS SEMICONDUCTOR	PCA82C250TD
U4	1	Schmitt Inverter / SOIC-14	ON SEMICONDUCTOR	MC74AC14DG
U5	1	8-bit HCS08 Controller / LQFP-44	FREESCALE SEMICONDUCTOR	MC9S08JM60CFGE
U6	1	3-Phase Bridge Driver / 54 SOICW-EP	FREESCALE SEMICONDUCTOR	MCZ33927EK
U7	1	Step-Down Regulator / SOIC-8	NATIONAL SEMICONDUCTOR	LM2594HVM-5.0/NO PB
U8	1	Voltage Regulator / SOIC-8	ON SEMICONDUCTOR	MC33269D-3.3G
X1	1	8 MHz Crystal / HC49	RAKON	LF A140E





## **Appendix C.**

### **3-Phase BLDC/PMSM Low-Voltage Motor Control Drive Layouts**

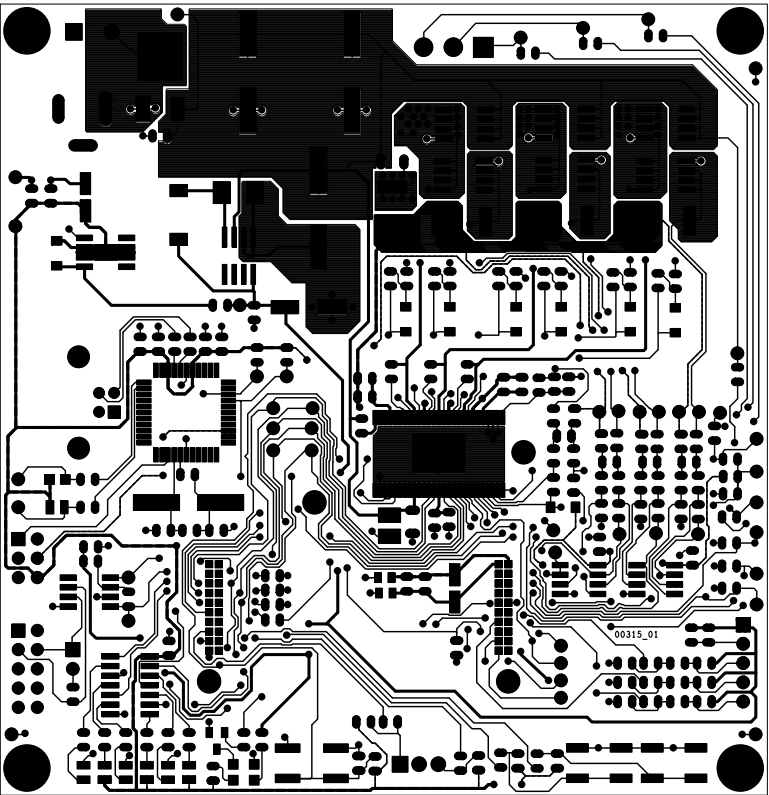
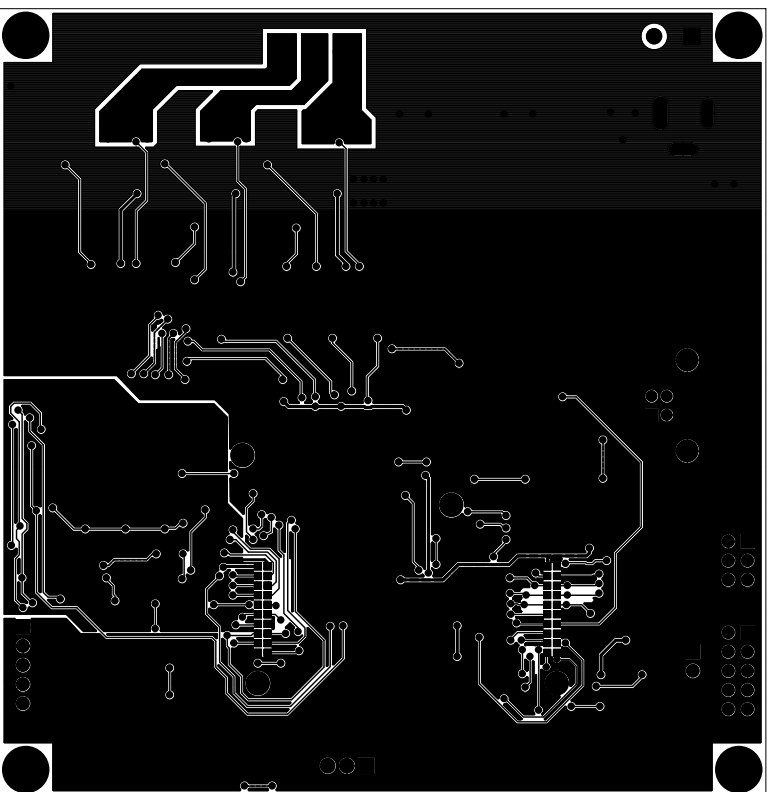


Figure C-1 Board Top Layer



**Figure C-2 Board Bottom Layer**

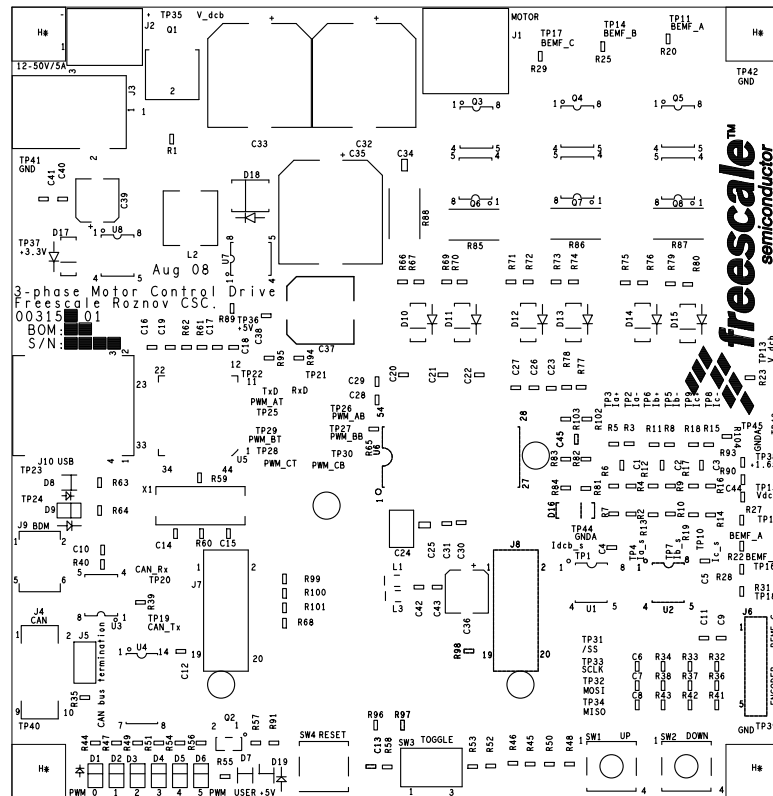
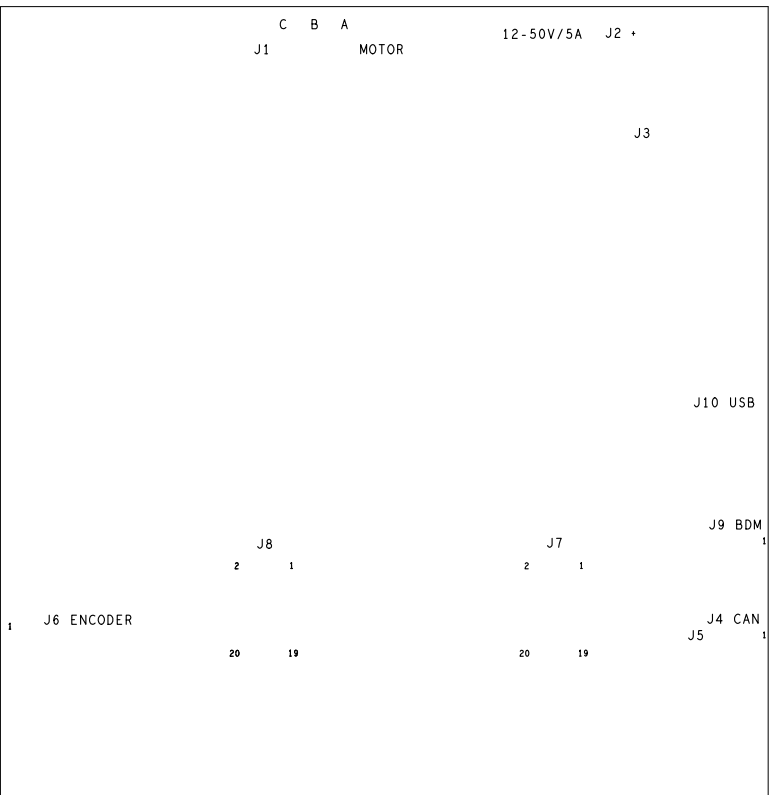


Figure C-3 Board Silkscreen Top Layer



**Figure C-4 Board Silkscreen Bottom Layer**







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